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A subsystem based probabilistic approach for the assessment of transmission capital project reliability impacts

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ABSTRACT

An efficient probabilistic approach for the assessment of transmission capital project impact is presented. The approach employs a subsystem based technique and takes advantage of the calculation accuracy of widely used commercial program for power flow analysis and accounts for equipment failure probability, variation in bus load, outage consequences and other system specific characteristics such as remedial action plan, specific operating procedures, tapped line and common mode failures. The approach also uses efficient computing techniques such as the breadth-first search algorithm and the recursive invocation method to facilitate the evaluation process. The proposed method is illustrated by evaluating and comparing several actual utility projects. The approach proposed in this paper will facilitate more realistic evaluation of large practical power systems using probabilistic methods.

1. Introduction

Power industry is facing many challenges due to the increasing rate of load growth, open market competition, demanding regulatory requirements and aging infrastructure. In order to address these challenges, utility companies are developing various plans for mitigating potential issues. These issues may include but are not limited to equipment overloads and deteriorating system voltages due to load growth, the impacts of system expansion such as increased fault currents, end-of-life, safety or environmental issues associated with deteriorating or obsolete assets as well as potential financial penalties resulting from violations of applicable reliability standards enforced by regulatory bodies such as the North American Electric Reliability Corporation (NERC) [1]. Addressing these issues requires large amount of dollars, may span several years, and in some cases involves environmental licensing and property rights acquisition. Most utility companies are, however, under tremendous financial pressure due to limited budget and resources. As a result, electric power industry has had to re-examine the priorities of the planned projects and to develop new approaches to quantify the impacts of the projects on the reliability performance of power systems.

The conventional probabilistic approaches for transmission system or composite generation and transmission system planning can be broadly categorized into either an analytical method or a Monte Carlo simulation technique [2,3]. Due to the increased complexity of modern power system the traditional methods have become more difficult than before in applications to practical power systems. As a result, the development of new and efficient techniques for quantifying the risk associated with electric transmission and/or composite power systems is attracting more and more attention particularly in the academia. Analytical techniques such as the fast sorting method [4], the Markov cut-set method [5] and the methods based on Bayesian Networks [6,7] are reported in literature. Enhanced approaches based on Monte Carlo simulation are also proposed including variance reduction technique [8], state-space partitioning [9], subset simulation [10], state space classification [11], cross-entropy [12], Latin Hypercube sampling [13] and other techniques [14,15].

Over the years considerable efforts have also been devoted to the use of some of the above-mentioned risk based or probabilistic approaches for the impact assessment of independent power producers, transmission expansion, maintenance scheduling and distribution system enhancement. A Monte Carlo simulation method is proposed to simulate the Danish power system performance considering the specific issues resulting from the liberation of the utility business [16]. The emphasis is given to model and evaluate the impacts of various independent power producers including wind power. A DC power flow is used to perform

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load flow analysis. A probabilistic method for the determination of the best transmission system expansion plan is proposed in [17,18]. The technique proposed in [17,18] treats the problem as an optimization process in which reliability is one of the constraints. A probabilistic branch and bound algorithm, which includes a DC network solution method, and the maximum flow-minimum cut set theorem are used to solve the problem. An optimization method for selecting and scheduling power system equipment maintenance under constraint resources is proposed in [19]. The method proposed in [19] employs a sequential Monte Carlo simulation technique to evaluate the reductions in risks due to maintenance subject to constraints on resources. Probabilistic approach using Monte Carlo simulation for transmission reinforcement considering large-scale wind farms is presented in [20]. An analysis technique for the prioritization of equipment maintenance strategies considering the physical condition of equipment and its contribution to the overall system reliability is presented in [21]. The technique could introduce significant errors because the potential load interruptions were estimated by system operators based on their experience rather than on a complete power flow analysis. Similar risk based approaches using analytical technique [22] and Monte Carlo simulation [23] are proposed for risk assessment and investment in distribution systems.

Most of the research described in the existing literature focuses on analyses of simple example power systems to illustrate the concepts, models and techniques using a risk based or probabilistic approach in transmission and/or composite system reliability evaluation. Relatively limited efforts are devoted to extending these models and techniques in large practical power system analysis [24,25]. Applications of composite system reliability assessment in a widely known academic system as well as on a large Brazilian power system are presented in [24]. A similar transmission planning approach based on a pruning technique is proposed to perform large practical system reliability assessment [25]. In addition, a DC power flow solution is commonly used for simplicity in existing literature but it could not capture the impacts of potential loss of load due to reactive power shortage or voltage violations. Although a number of commercial programs and various computing techniques for performance assessment of large power systems are available, little work has been done to utilize these existing commercial programs and computationally-efficient methods to facilitate the probabilistic evaluation of large practical electric power systems. The proposed approach expands the industry knowledge in the area taking advantage of calculation accuracy of widely used commercial programs and various effective methods for example a subsystem based approach to perform probabilistic or risk-based assessment of practical transmission systems. The proposed approach also uses efficient computing techniques for example the breadth-first searching algorithm [26] and recursive invocation method [27] to facilitate the evaluation process. The impact of a particular transmission project is quantified by calculating the expected unserved energy difference (ΔEUE) of transmission scenarios with and without the planned project. In this way, each transmission project can be evaluated, ranked and prioritized on a common base using the ΔEUE. The approach proposed in this paper will facilitate more realistic evaluation of large practical power systems using probabilistic methods.

This paper is arranged as follows. Section 1 is the introductory information. Section 2 describes the proposed approach in detail and rigorous mathematical equations for the various techniques used in facilitating the evaluation process. The application of the proposed method is illustrated by evaluating several actual utility projects in Section 3. The conclusions drawn from the studies described in this paper is highlighted in Section 4.

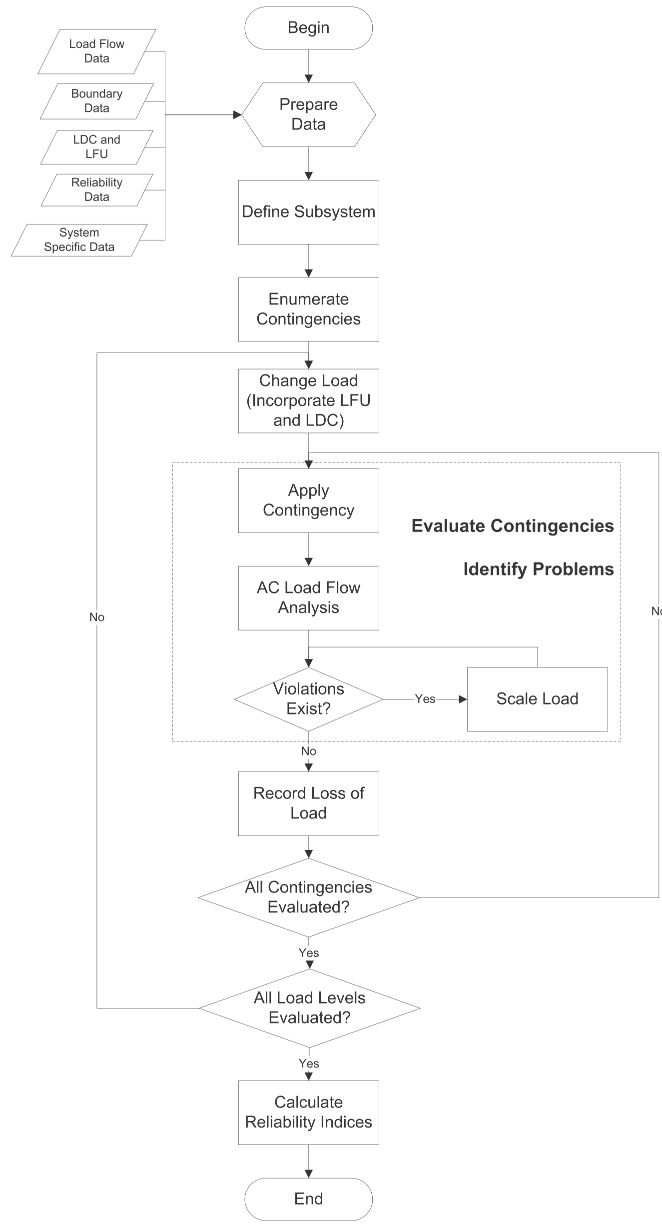

Fig. 1. Proposed methodology.

2. Description of the methodology

A large number of scenarios and contingencies need to be evaluated in a probabilistic assessment of power systems in order to incorporate the impacts of various uncertainties associated with system operating conditions, load and component failures [28,29]. This inherently poses a significant amount of computational burden particularly in the assessment of practical large power systems. A subsystem based approach is, therefore, proposed in the research described in this paper. The core of the proposed approach is to call the various functionalities of widely used commercial tools using external programs to perform a probabilistic assessment of large power systems. The basic idea of the proposed methodology is illustrated in Fig. 1. The entire process involves data preparation, subsystem definition, contingency enumeration, contingency evaluation using AC load flow and problem identification, incorporation